A Synoptic Analysis of the 7-11 January 2005 Southern California Flood Event

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Abstract

Atmospheric rivers (ARs) are high-impact, long-duration precipitation events that bring significant rain and snow to California through the concentrated transport of moist, tropical air. This case study analyzes a high-precipitation event that affected southern California from 7 January 2005 thru 11 January 2005, bringing upwards of 80 cm of rain to high elevations. A blocking pattern in the central Pacific inhibited zonal flow downstream, providing forcing for a trough to amplify off the coast of Oregon. As a surface low developed in association with this upper-level trough, it and several smaller disturbances off the southern California coast aided in the set-up and persistence of a landfalling AR.

Introduction

Atmospheric rivers (ARs) are long, narrow corridors of concentrated water vapor transport that bring warm, moist tropical air from low latitudes to mid latitudes (Neiman et al. 2008). They develop in association with the warm conveyor belt of extra-tropical cyclones and can stretch for several thousands of kilometers, often bringing significant precipitation to areas where they make landfall (Newman et al. 2012). ARs have been linked in particular to extreme flooding and heavy snowpack along the west coast of North America and have been shown to contribute to upwards of 50% of annual winter precipitation in these areas (Neiman et al. 2008, Dettinger et al. 2011). Due to their
intensity, more than half of persistent droughts along the West Coast have ended as a result of a landfalling AR (Dettinger 2013).

Wintertime ARs have been associated with several common synoptic features: strong water vapor flux in a pre-cold frontal environment, anomalous warmth, an offshore trough, and ridging over the Intermountain West (Neiman et al. 2008). ARs have greater extreme precipitation and related impacts during the winter along the west coast of North America due to stronger vapor flux, greater tendency toward saturation, and deeper cyclones off the coast. Due to the mountainous topography of the West Coast, ARs have been linked with significant orographic enhancement, with mountainous regions receiving upwards of three to four feet of rain during the most extreme landfalls (Neiman et al. 2008). Depending on the extent of cold air in place when an AR makes landfall, ARs can produce several feet of snowfall at high-altitude locations, enhanced by orographic effects and with increased snow-water equivalents (Smith et al. 2010).

Flooding is a concern as with warmer air in place, an AR can produce excessive rain totals on preexisting snowpack.

ARs are of particular concern in California due to the state’s recent growing water demands and high risk of flood hazards (Dettinger et al. 2013). Often fueled by strong landfalling ARs, California receives some of the largest 3-day precipitation totals in the United States, posing significant risks to its residents in flood-prone areas.

This paper thus focuses on the 7-11 January 2005 flood event in Southern California, in which storm totals exceeded 80 cm in the wettest locations (NOAA storm summaries 2005). While on its own significant, this event took place only weeks after a prior AR event that produced 25-50 cm of precipitation across much of the same area,
from Point Conception south to Orange County. During the January event’s peak, rainfall rates near Ojai, CA exceeded 5 cm per 6 hours consecutively for a 36-hour period – flooding and landslides were widespread. To investigate this long-duration landfalling AR, this paper will analyze the synoptic setup prior to and during the event. Jet-level dynamics, precipitable water (its transport and anomalies), trajectories, and surface analyses will be examined.

**Methods**

Upper-level dynamics were interpreted using Climate Forecast System Reanalysis (CFSR) gridded data at three time intervals: 0000 UTC on 7 January 2005, 9 January 2005, and 11 January 2005. 250-hPa winds speeds were used to calculate the upper-level jet and were used in conjunction with 250-hPa geopotential heights. 250-hPa winds were partitioned into their irrotational and non-divergent components, with the irrotational component used to analyze divergent outflow associated with lower-level cyclones. CFSR data was further utilized to plot sea level pressure, precipitable water, and the 700-hPa wind field to examine lower-level dynamics and orographic influences. Standardized anomalies of precipitable water were calculated and time-averaged over the entire period of the event (7 January 2005 thru 11 January 2005). The NOAA HYSPLIT model was used to determine air parcel trajectories into Los Angeles, CA at 500 m, 3000 m, and 10,000 m using NCEP-NCAR Reanalysis data and calculated using the model vertical velocity method. For a multi-level mesoscale analysis, upper-air soundings from Vandenberg Air Force Base (VBG) and San Diego, along with daily precipitation totals with a 10 km resolution were obtained from the California Nevada River Forecast Center.

**Results**
Period 1: 0000 UTC – 1200 UTC 7 January 2005

Prior to the onset of the event, a high-latitude omega block had developed upstream, centered over western Alaska, with a strong jet of up to 80 ms$^{-1}$ at 0000 UTC 7 January 2005 (Fig. 1). This blocking pattern provided forcing for the development of a trough downstream, located off the Washington coast, with small divergent outflow aloft as seen through the irrotational wind. Associated with this divergent outflow and downstream of the trough off the Washington coast was a surface cyclone of 1004 hPa (Fig. 2). To the south, a 996 hPa cyclone off the central California began pulling high levels of precipitable water from the tropics, with values of 30 mm or greater approaching the southern California coast. By 1200 UTC 7 January 2005, the atmosphere was completely saturated from the surface up to 650 hPa at VBG (Fig. 3). SE winds at the surface veered with height to WSW winds at mid- and upper-levels, providing for warm air advection to begin entering the region. As this AR made landfall, it produced heavy precipitation along the coast, with values in Los Angeles approaching 4 cm through 4AM 8 January 2005 (Fig. 4). Mountainous regions to the north and south saw values upwards of 10 cm in 24 hours.

Period 2: 0000 UTC 9 January 2005

By 0000 UTC 9 January 2005, the persistent omega block continued to inhibit zonal flow into the western United States (Fig. 5). Diabatic heating associated with a cyclone in the poleward exit region of a jet streak to the south of the block continued to build the ridge into polar latitudes, as seen through the “starbust” pattern in the irrotational wind. As the ridge amplified, the downstream trough located off the Oregon coast deepened and pushed further south. Upper-level QG forcing for ascent increased off
the southern California coast, with the region located in the poleward exit and equatorward entrance regions of a split jet.

Associated with the upper-level trough, the surface cyclone seen in the previous time period off the coast of Oregon strengthened to 988 hPa (Fig. 6). Cyclonic flow around the low pressure continued to advect an AR of high precipitable water values toward the southern California coast, with 700-hPa winds now blowing from the southwest at 20-25 ms\(^{-1}\), perpendicular to coastal mountain ranges. A series of weak disturbances near 30°N began to push eastward towards the coast, pulling in additional moisture from the tropics. 24-hour HYSPLIT backwards trajectories at 500 m, 3000 m, and 10,000 m in Los Angeles, CA originated from the Pacific Ocean to the west and between 25°N and 30°N (Fig. 7).

The atmosphere at VBG continued to be saturated up to 700 hPa, with a low-level jet of 50-60 kt persisting from the SW, perpendicular to mountains (Fig. 8). Warm air advection persisted, with winds veering with height from SSW at the surface to W at mid-levels. With the AR still making landfall on the southern California coast, a large swath of heavy precipitation encompassed the region, with 24-hour values ranging from 4 cm in San Diego to 10 cm in Ventura County (Fig. 9). Further inland, higher elevations saw precipitation amounts ranging from 10 cm to 15+ cm, with amounts falling drastically on the lee side of mountains.

Period 3: 0000 UTC 11 January 2005

At 0000 UTC 11 January 2005, the omega block had weakened as its associated ridge had dropped in latitude and gained a negative tilt (Fig. 10). The downstream trough began to separate from a more zonal flow to the north and was then located off the coast
of northern California. Southern California remained in the poleward exit region of a
low-latitude jet, with some divergent outflow aloft.

While still lingering off the coast of northern California, a surface low pressure
system had weakened, with a central pressure of 1002 hPa (Fig. 11). It continued to aid in
the transport of precipitable water from the tropics in the way of an AR, but values were
primarily 20 mm or less at this time. Winds at 700-hPa had decreased, but persisted from
the SW at 15-20 ms\(^{-1}\).

As the surface low pressure and moisture transport weakened, saturated air
remained only from the surface up to 900 hPa at VBG, with dry air being advected from
the west at mid-levels (Fig. 12). Warm air advection occurred at a shallower level at this
time, with winds beginning to back near 850 hPa before veering again at 750 hPa. Further
south, air remained closer to saturation at NKX near San Diego, with veering winds and
warm air advection up to 650 hPa (Fig. 13). With greater moisture present near San
Diego, 24-hour precipitation totals ranged from 2-5 cm near the Mexico border to less 0.5
cm from Los Angeles northward (Fig. 14).

Precipitable Water Anomalies 0000 UTC 7 January – 0000 UTC 11 January 2005

Standardized precipitable water anomalies over the duration of this event ranged
from +3.0 SD near San Diego, CA and Orange County, CA to a widespread area of +2.5
SD over the rest of Southern California (Fig. 15). These positive anomalies persisted
through the Pacific Ocean to the SW for several hundred km, along the axis of the
landfalling AR.

Discussion and Conclusion
The extreme rainfall event that occurred in Southern California from 7 January 2005 thru 11 January 2005 transpired due to a persistent landfalling AR that brought the transport of moist air from the tropics over an extended period of time. As Doswell et al. (1996) stated, high precipitation totals result not only from high precipitation rates but also from the duration of a rainfall event. While irrotational winds show little evidence of extensive convection near the surface, unremitting stratiform rain was likely the key player is such high precipitation totals. As the upper-level trough and associated surface cyclone remained nearly stationary off the Oregon coast due to a high-latitude omega block over Alaska, a series of small disturbances pushed into the southern California coast from the west. As this group of cyclones continuously brought moisture from the tropics, the AR continued to make landfall, bringing extensive rains and flooding to the region. Trajectories revealed that all levels received an influx of parcels from the SW. With warm, moist maritime tropical air reaching California, there was additional forcing for greater ascent and therefore even greater precipitation amounts.

A strong low-level jet, with winds exceeding 60 kt at the peak of the event, along with moisture transport oriented from the SW (perpendicular to southern California’s mountain ranges), provided strong orographic forcing and enhanced rainfall totals, similar to the process described in Neiman et al. (2008). With this SW low- to mid-level flow lasting for five days, and with continuous warm air advection, high elevations received upwards of 80 cm of rain, while valley locations generally received less than 35 cm (still significant).

While this case study does agree with major aspects of previous AR papers, there are some notable differences. Unlike the composite analysis performed by Neiman et al.
(2008), there is little to no ridging over the Intermountain West, and most of the precipitation did not occur in association with a front. Future work could be done to analyze blocking patterns in the N. Pacific and note any correlations to ARs, and to see if these events have any different spatial or temporal aspects compared to traditional AR cases, e.g. the low-latitude and long duration of this event.

References


Appendix

250-hPa Geopotential Height, Jet & Irrotational Wind

![Image of 250-hPa Geopotential Height, Jet & Irrotational Wind](image1)

**Figure 1:** 250-hPa irrotational wind (ms$^{-1}$), jet (ms$^{-1}$), and geopotential height (m) at 0000 UTC 7 January 2005

Sea Level Pressure, Precipitable Water & 700-hPa winds

![Image of Sea Level Pressure, Precipitable Water & 700-hPa winds](image2)

**Figure 2:** Sea level pressure (hPa), precipitable water (mm), and 700-hPa wind barbs (ms$^{-1}$) at 0000 UTC 7 January 2005
Figure 3: Upper-air sounding taken at Vandenberg Air Force base at 1200 UTC 7 January 2005
Figure 4: 24-hour precipitation totals (in) from 4AM 7 January 2005 – 4 AM 8 January 2005
Figure 5: 250-hPa irrotational wind (ms$^{-1}$), jet (ms$^{-1}$), and geopotential height (m) at 0000 UTC 9 January 2005

Figure 6: Sea level pressure (hPa), precipitable water (mm), and 700-hPa wind barbs (ms$^{-1}$) at 0000 UTC 9 January 2005
Figure 7: NOAA HYSPLIT backwards trajectories ending in Los Angeles, CA at 500 m (red), 3000 m (blue), and 10,000 m (green)
Figure 8: Upper-air sounding taken at Vandenberg Air Force base at 0000 UTC 9 January 2005
Figure 9: 24-hour precipitation totals (in) from 4AM 9 January 2005 – 4 AM 10 January 2005
Figure 10: 250-hPa irrotational wind (ms$^{-1}$), jet (ms$^{-1}$), and geopotential height (m) at 0000 UTC 11 January 2005

Figure 11: Sea level pressure (hPa), precipitable water (mm), and 700-hPa wind barbs (ms$^{-1}$) at 0000 UTC 11 January 2005
Figure 12: Upper-air sounding taken at Vandenberg Air Force base at 0000 UTC 11 January 2005

Figure 13: Upper-air sounding taken in San Diego at 0000 UTC 11 January 2005
Figure 14: 24-hour precipitation totals (in) from 4AM 11 January 2005 – 4 AM 12 January 2005
Figure 15: Standardized precipitable water anomalies (σ) time-averaged from 0000 UTC 7 January 2005 thru 0000 UTC 11 January 2005